Virginia Tech Team Rocky

DARPA Grand Challenge 2005

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1. Vehicle Description

1.1. Describe the vehicle. If it is based on a commercially available platform, provide the year, make, and model. If it uses a custom-built chassis or body, describe the major characteristics. If appropriate, please provide a rationale for the choice of this vehicle for the DGC.

The Virginia Tech base platform is an Ingersoll-Rand Club Car XRT-1500. Rocky is a 2005 diesel model. Virginia Tech has expanded the fuel capacity for longer operation and added a reinforced and expanded roll cage to accommodate and protect the sensitive electronics onboard. This vehicle suits our application well with an 11.5’ turning radius, top speed of 25mph, and high (>800lb) cargo capacity.

1.2. Describe any unique vehicle drive-train or suspension modifications made for the DGC including fuel-cells or other unique power sources.

The only suspension modification to the Club Car was the installation of a heavy-duty spring upgrade and anti-sway bars. These are available from Ingersoll-Rand as an aftermarket kit.

2. Autonomous Operations

2.1. Processing

2.1.1. Describe the computing systems (hardware and software) including processor selection, complexity considerations, software implementation and anticipated reliability.

Computational power on Rocky is distributed across four National Instruments PXI-8176 controllers. Using PCI electrical-bus features, PXIs are a high-performance and low-cost method for measurement and autonomous control. These computers range in speed from 1.26 to 2.6 gigahertz, and can withstand shocks of up to 30 g’s. With this fairly high resistance to shock, the PXI chassis can be rigidly mounted inside the electrical box without fear of damage. These platforms excel in interfacing with sensors. Using the embedded control feature of the PXI eliminates the need for external computers for vehicle control.

Windows XP runs on all three computers. While running XP can create problems due to the extra peripherals, it allows all team members to interact with Rocky. By removing all unnecessary features of the Windows operating system, we increase the stability of the computers while maintaining an easy to use interface to all team members.

The software on Rocky was created using National Instruments' Labview 7.1. This programming language allows team members with knowledge of control systems but little programming experience to program the vehicles behavior. Certain parts of the programs are written in C; however, these pieces are converted into .dll files that are used by the larger Labview code. Another large benefit of using Labview is the ease of creating vehicle interfaces within the programs. Any team member can easily create an interface that monitors all vehicle action and sensor data during autonomous operation. This allows for quick and easy debugging to any problems that appear during testing.

2.1.2. Provide a functional block diagram of the processing architecture that describes how the sensing, navigation and actuation are coupled to the processing element(s) to enable autonomous operation. Show the network architecture and discuss the challenges faced in realization of the system.

Rocky's sensing, navigation, and actuation are controlled with four computers (mounted in the vehicle as illustrated): path planning, stereo vision, INS/local mapping, and motion control. Using the INS/Local Mapping computer, autonomous operation begins with the vehicle determining its current position and locating its destination. The vehicle also evaluates its surroundings using LIDAR. The LIDAR uses a laser to scan the area in front of the vehicle to detect obstacles. With each scan, it returns the distance to all of the obstacles it sees in the vehicles path. Using the INS and LIDAR, a local map is created to show all of the visible obstacles with respect to the vehicle. The stereo vision camera also monitors what is happening in front of the vehicle. The vision is used to determine whether or not there is a road to follow that will benefit travel through the RDDF corridor.

The Path Planning computer then determines the best path to take using both the local map and road map. The desired commands are then sent to the Motion Control computer. This computer double checks the safety of the commands with its current conditions. It sends a brake percent, throttle percent, and steering angle to the actuators in order to provide the desired safe motion. Figure 1 displays a block diagram of this processing architecture.

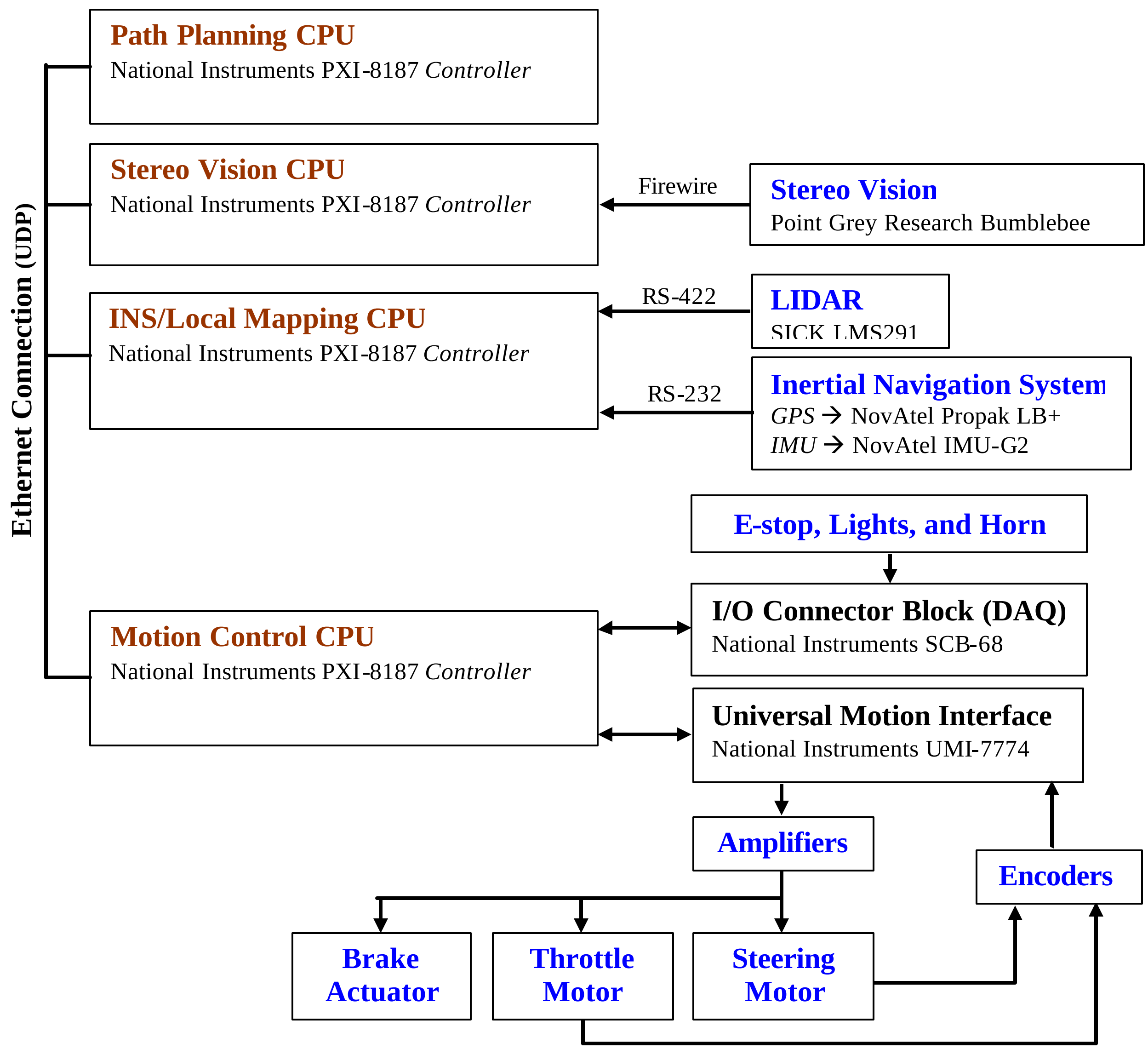

Figure 1. Block diagram of the processing architecture for the vehicle's sensing, navigation, and actuation

The computers on the vehicle are networked via an Ethernet connection. Using UDP communication, the computers can send the needed information to one another. Figure 2 illustrates the network architecture and the information that is passed between each computer. The major challenge we faced with our network has been how to handle communication failure. Since our main source of speed feedback comes from the ProPak INS, it is extremely important to make sure we are receiving the correct data. We have not experienced a failure with our current UDP communication setup but to be safe we still perform the INS data check.

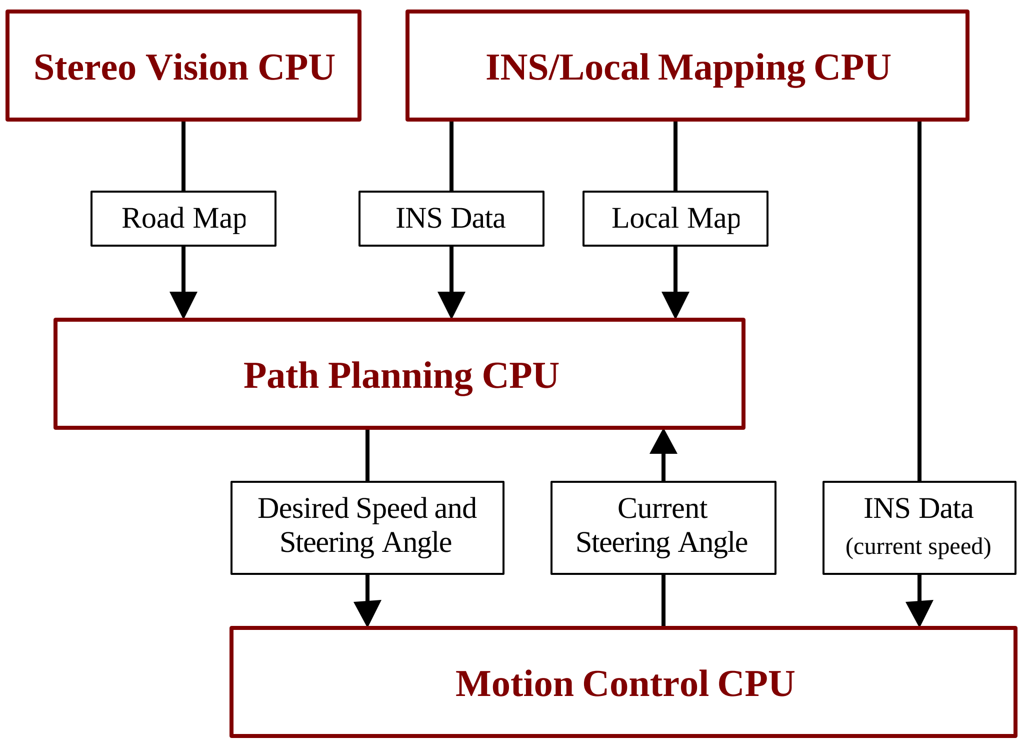

Figure 2. Network architecture

2.1.3. Describe unique methods employed in the development process, including model-driven design or other methods used.

Rocky underwent extensive simulated and live testing in preparation for the 2005 Grand Challenge. Most live testing took place in an approximately 75 acre field in Blacksburg, Virginia. This area allowed for various courses to be set up where Rocky was exposed to hills, rough terrain, and dirt roads. Numerous long-term tests were also conducted in order to test the mechanical, electrical, and software reliability. In these tests, Rocky was run in autonomous mode over a looped course until a fault caused it to stop. By running these tests, long term software and hardware reliability could be determined, and changes could be made to allow the vehicle to run for longer periods of time.

A vehicle simulator program was also designed to test conditions and situations that would be difficult, if not impossible, for Rocky to encounter in Blacksburg. This program creates a virtual map and sensor data that is relayed to the actual pieces of software that control the vehicle. This simulator, along with information about Rocky's vehicle dynamics, tested the algorithms in a virtual space before ever placing them on the vehicle. It also allowed for testing during conditions where it would normally not be possible, such as at night or during heavy rain. In order to attempt and simulate the desert environment that will be seen at the Grand Challenge, Rocky was taken to deserts in Arizona and Texas for testing once it performed reliably in the field environment. Rocky was run in various desert conditions such as heavy dust clouds and high temperatures in order to observe the impact a desert environment would have on the vehicle.

A second set of testsoftware allowed various data recorded from the vehicle to be replayed for analysis. This replay software played back information such as vehicle position and orientation, speed, throttle and brake percentages, and LIDAR scans at the same speed that it was originally recorded. Being able to play back exactly what happened during autonomous runs was valuable to see exactly how Rocky behaves in the real world.

2.2. Localization

2.2.1. Explain the GPS system used and any inertial navigation systems employed during GPS outages (as in tunnels). Include a discussion of component errors and their effect on system performance.

The GPS system used on Rocky is a Novatel Propak LBplus system. The LBplus system alone can provide position accuracy of 1.5 meters CEP (Circular Error Probable). To improve the position accuracy, the system uses Omnistar HP differential corrections, which improves the accuracy of the system to 0.10 meters CEP.

In addition to the high position accuracy of the Propak LBplus system, this unit also has inertial measurement unit (IMU) support. The IMU onboard Rocky is a Honeywell HG1700 AG11. This IMU has a gyro bias of only 1 deg/hr. Using this system, Rocky will be able to maintain position accuracy during GPS satellite signal outages. The Propak LBplus system is configured to provide an INS position solution at 20 z. This solution is updated with the Omnistar HP position solution at 1 Hz.

2.2.2. If map data was an integral part of the vehicles navigation system, describe the requirements for this data and the way in which it was used.

No global map data was used in Rocky's navigation system.

2.3. Sensing

2.3.1. Describe the location and mounting of the sensors mounted on the vehicle. Include a discussion of sensor range and field of view. Discuss any unique methods used to compensate for conditions such as vibration, light level, rain, or dust.

Rocky uses three scanning LIDAR and a Stereo vision camera. All sensors are rigidly mounted to the vehicle. The Stereo vision camera is also equipped with a visor to shield it from the sun.

Two Sick single plane scanning LIDAR are mounted to the top left and right front corners of the vehicle. This configuration provides a larger scanning area in front and to the sides of the vehicle. The top two scanners are used to create a terrain map of the surrounding the vehicle.

The third LIDAR is an IBEO ALASCA and is mounted in the front center of the vehicle. This LIDAR unit has four scanning plans, allowing for enhanced obstacle detection. The obstacle data from the ALASCA is added to the terrain map.

The stereo vision camera is a Point Grey Bumble Bee. The camera is mounted in the top center of the vehicle. This is an ideal vantage point for detecting roads in front of the vehicle.

To eliminate the problem of dust and rain we have two approaches. The ALASCA is able to detect solid obstacles and see through the dust and rain. The SICK LMS-291 LIDAR systems do not have the same capability. Prevent failure due to false obstacles by stopping the vehicle when there appears to be no traversable route forward until the more reliable ALASCA indicates obstacle in front of the vehicle. The terrain map created by the LMS-291 sensors is cleared and started over again to get rid of any spurious from the scanners because of dust or rain. To compensate for varying light conditions on the Bumble Bee stereo vision camera, the vision processing algorithm uses active adaptive gain control and learning. In addition, the vision software will not output road points if excessive glare or other conditions reduce the reliability of the identified road points.

2.3.2. Discuss the overall sensing architecture, including any fusion algorithms or other means employed to build models of the external environment.

All sensor data collected by Rocky is processed by the computer on which it is collected then sent as a local cost map for terrain traversibility to the path planning computer. The maps from each sensor are overlaid onto a master map that includes course boundaries and waypoints. The path planning computer then chooses an optimal path through the perceived road, obstacle, and waypoint map.

2.3.3. Describe the internal sensing system and architecture used to sense the vehicle state.

Rocky uses an onboard accelerometer array with a temperature sensor located in the electronics enclosure to measure the conditions to which the vehicle electronics are subject. Battery voltage is also logged on the vehicle's power system. All of these are recorded on the vehicle computers using a National Instruments USB DAQ. This information does not affect the vehicle's navigation behavior.

2.3.4. Describe the sensing-to-actuation system used for waypoint following, path finding, obstacle detection, and collision avoidance. Include a discussion of vehicle models in terms of braking, turning, and control of the accelerator.

All sensor data collected by Rocky and added to a local map of traversability costs. An area of sharp change in perceived altitude by our LMS-291 rangefinders is given a high cost while an area recognized as a road by our vision system is given a low cost. From this data, our path planning computer chooses the optimal perceived path to the next waypoint. Based on this path, the path planning computer relays the desired speed and steering angle to the Motion Control computer, which uses custom PID controls to control speed and steering position.

2.4. Vehicle Control

2.4.1. Describe the methods employed for common autonomous operation contingencies such as missed-waypoint, vehicle-stuck, vehicle-outside-lateral-boundary-offset, or obstacle-detected-in-path.

The vehicle will perform whatever turning maneuvers necessary to reach the designated waypoint safely. In the event the vehicle is physically immobilized, there are no contingencies to solve the problem. There are no self-righting mechanisms in place for roll-overs. If the vehicle is stuck and is registering a zero velocity, it will continue to apply more throttle until it starts moving again. In the case where the vehicle enters a cul-de-sac, Rocky will skirt the edge of it until it can exit.

Rocky uses the A* algorithm to generate the best path through the local cost map it creates. If there is an obstacle in the path of the vehicle, the algorithm will draw a path around it for the vehicle to follow. Use of the A* algorithm allows any area outside of the lateral boundary offset to have a high cost associated with it on the vehicle's generated map. The vehicle will only exit the corridor to avoid an impassable obstacle. In the event that it does go out of bounds, it will immediately enter the corridor after avoiding the obstacle.

2.4.2. Describe the methods used for maneuvers such as braking, starting on a hill, or making a sharp turn without leaving the route boundaries.

As described in the previous section, the vehicle uses the A* algorithm to stay within the boundaries. Any areas outside the corridor are given a high enough weighting to ensure that the vehicle only leaves the route boundaries if an obstacle is obstructing the entire boundary corridor. Rocky will slow down using brakes to take the sharpest possible turn if necessary.

2.4.3. Describe the method for integration of navigation information and sensing information.

The LIDAR configuration on Rocky generates a terrain map with costs associated to each grid. A grid unit with lower costs means the terrain is easier to traverse. The stereo vision camera will adjust the map costs to include road data. Areas that are recognized as roads will be lowered in cost to favor road following. The final map building process involves adding higher costs to areas outside the route boundaries based on GPS and INS information.

Once the map has been updated for the current cycle, the vehicle position on the map is designated as the start point for the A* algorithm and the goal point is assigned based on the position of the next waypoint. The algorithm draws the path of least cost through the map and the vehicle will steer to follow that path. Speed is controlled using INS data, desired steering angle, and the density of obstacles within the map.

2.4.4. Discuss the control of the vehicle when it is not in autonomous mode.

The onboard joystick is used to control the vehicle when it is not in autonomous mode. The input is read from two of the axes on Rocky's USB joystick. This allows the driver to command a desired steering angle and throttle percent. These values are then sent to the actuators just as if the autonomous controls had commanded it.

The vehicle also has two pedals that control two different brake systems. There is a control brake pedal that, like the joystick, is an analog input that ties into the computer control system. The driver can use this pedal to control the brake percent that is commanded to the brake actuator. No matter what mode the vehicle is in, the control brake pedal has the ability to override the commanded brake percent. The second pedal is the manual brake that uses the mechanical brake system that came with the vehicle. This provides a way for the driver to stop the vehicle if there is a computer failure.

Rocky has five modes: (1) Stop, (2) Joystick, (3) Computer Steering/Joystick Throttle, (4) Computer Throttle/Joystick Steering, and (5) Fully Autonomous. Stop mode simply commands zero to the steering, brake and throttle actuators. Joystick mode gives the driver full control of all three of the actuators. The next two modes are used mainly for testing and debugging purposes. Computer Steering/Joystick Throttle provides a way to test navigation while the driver has control of the vehicle speed. Computer Throttle/Joystick Steering provides a way to test speed control. Fully autonomous mode gives the control of all three of the actuators to the computers.

2.5. System Tests

2.5.1. Describe the testing strategy to ensure vehicle readiness for DGC, including a discussion of component reliability, and any efforts made to simulate the DGC environment.

Rocky was subjected to extensive simulated and live testing in preparation for the 2005 Grand Challenge. Most live testing took place in an approximately

75 acre field in Blacksburg, Virginia. This area allowed for various courses to be set up where Rocky was exposed to hills, rough terrain, and dirt roads. Numerous long-term tests were also conducted in order to test the mechanical, electrical, and software reliability. In these tests, Rocky was run in autonomous mode over a looped course until an error caused it to stop. By running these tests, long term software and hardware reliability could be determined, and changes could be made to allow the vehicle to run for longer periods of time.

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2.5.2. Discuss test results and key challenges discovered.

From the numerous tests that Rocky underwent, a number of key tests resulted in changes to the software and hardware. The main issued that appeared during testing was keeping the vehicle in the center of the corridor. Since the map originally gave the same weighting to any area inside the corridor, there was nothing to bring the vehicle back to the center of the course after avoiding an obstacle. This would result in Rocky swerving back and forth across the course as it detected minor changes in the path. In order to fix this problem, the center of the corridor was weighted lower than further off the centerline. This gave the centerline a lower cost than the rest of the corridor, and resulted in Rocky following the center of the course.

Other than numerous minor vehicle failures to correct and prevent, the biggest problem that arose was a lack of power from the onboard batteries. During long term testing sessions, suitable power was not being supplied to battery-controlled devices, such as the steering and throttle motors. It was discovered that the chargers used to re-supply the batteries with power during operation were not charging as fast as other systems were drawing power away. New chargers were purchased in order to ensure all devices on the vehicle receive adequate power at all times. Without running long-term tests, problems such as these would have never been discovered until the Grand Challenge itself.